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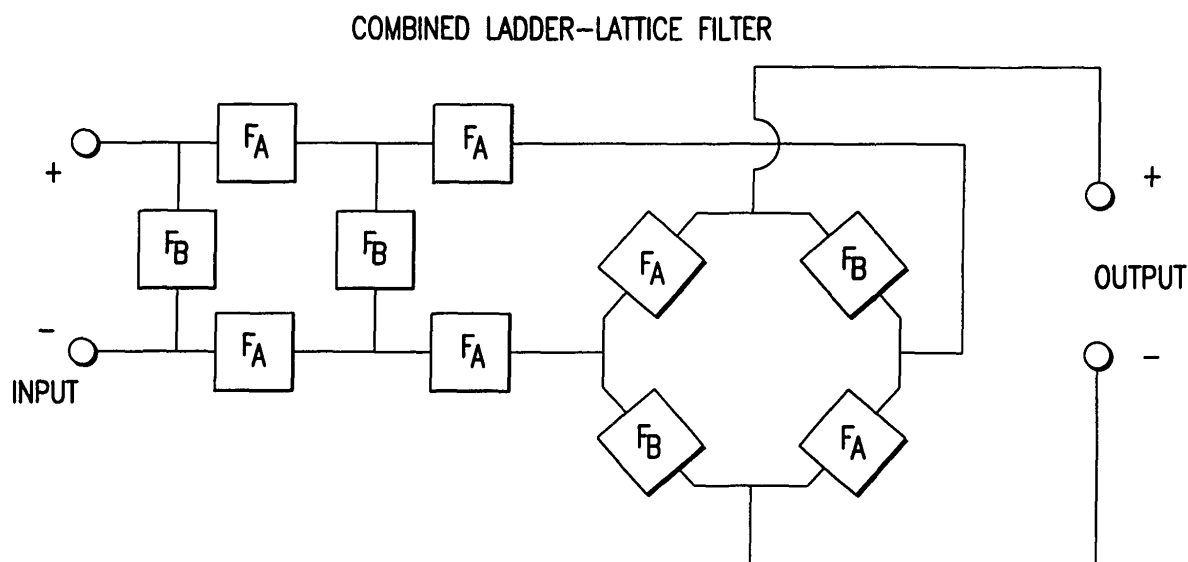
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(54) **An integrated filter balun**

(57) In one embodiment, an N-stage ladder circuit is serially connected to a bridge lattice circuit. The N-stage ladder circuit receives differential inputs, e.g. mixers, while the bridge lattice circuit outputs a singled end output, e.g. amplifier. In another embodiment, a bridge lattice circuit is serially connected to an N-stage ladder

circuit. The bridge lattice circuit receives a single ended load while the N-stage ladder circuit provides a differential output. Film bulk acoustic resonators are used in the combination ladder and lattice structure for both embodiments to provide the necessary band-pass functionality as well as make the necessary transition from differential to single ended load.



**FIG.4A**

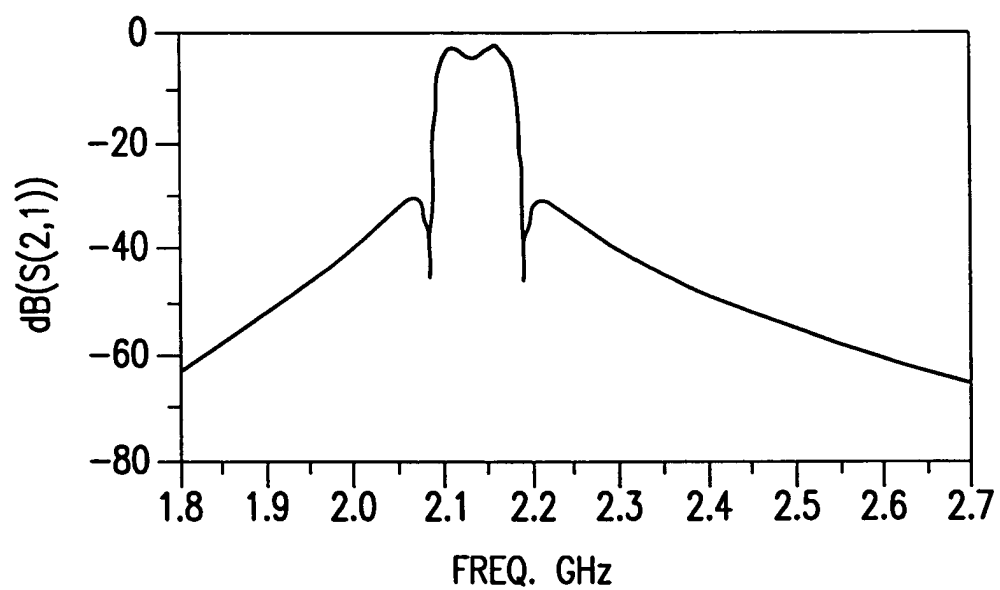


FIG. 4B

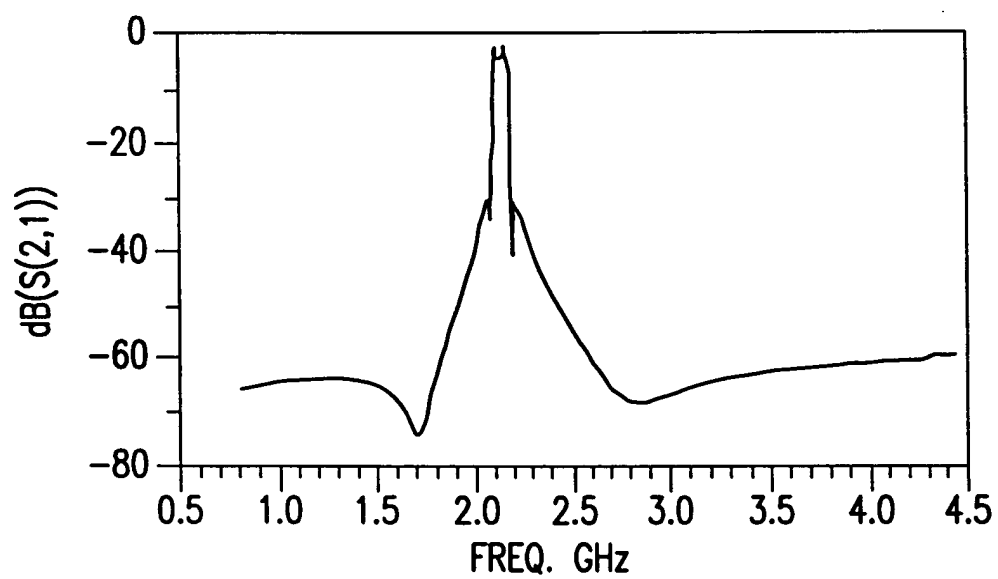


FIG. 4C

## Description

### Field of the Invention

**[0001]** The invention is directed towards the field of analog circuitry, particularly filters that manage the transition from differential to single-ended circuits.

### BACKGROUND OF THE INVENTION

**[0002]** The prior art uses two schemes for high frequency analog electronics: single ended and differential. In single-ended designs, the signal is referenced to the ground plane. Any design, e.g. mixing, amplifying, or signal generation, may be performed by a single transistor. This makes the single ended architecture the better choice for discrete implementation. Unfortunately, single-ended implementations have a great sensitivity to the electrical connection to the ground plane. The sensitivity increases proportional to the increase in frequency or power. Compensating for this sensitivity at high power and frequency can require tens to hundreds of bond wires connecting the transistor to the ground plane. Any inductance in the ground plane itself can cause signal leakage between different parts of the larger circuit.

**[0003]** In differential designs, the signal is referenced to two orthogonal arms of the circuit. Any connection to the ground plane is parasitic, and of much less influence. The circuit is much more complex, however, requiring at least three transistors for each function. Thus, differential circuits are virtually always integrated. Another disadvantage is that some voltage is lost in extra biasing elements. However, the isolating nature of the differential is such a significant advantage that the loss of headroom and increased complexity is tolerable.

**[0004]** There are two types of differential structures: ladder and lattice. These filters are typically built using lumped resonators, e.g. crystal resonators, LC resonators, and combinations of the two. These filters tend to be quite large and expensive, hence, too costly for high volume consumer electronic applications, e.g. cellular phones. Recent developments in resonant structures allow these complex circuits to be built in a cost-effective manner.

**[0005]** Current implementations of film bulk acoustic resonators (FBAR) filters are half-ladder, single-ended structures, as shown in Figures 1A-B. The helper inductors, shown in Figure 1B), move some of the rejection further into the reject bands to allow for broader frequency rejection. These helpers cause the rejection slope at the band edge to flatten, thereby reducing the rejection just out of band. The helpers also result in less rejection far out of band.

**[0006]** Figures 2A-E show embodiments of the prior art ladder circuits. Figure 2A is completely differential while Figure 2B has a ground reference. The ground reference increases the filter complexity but has common

mode rejection. They function similarly for differential operation. Figures 2C-D illustrate the filter response during differential operation. Figure 2C shows the close-in filter response while Figure 2D illustrates the broad-band response. The filter has a very steep rejection followed by a very fast flyback response. Figure 2E illustrates a ladder circuit using "helper" inductors. This is at the expense of increased complexity and cost. Similar to a half ladder circuit, the band edge rejection is worse. Figure 2D is shows two half ladder in parallel. This is twice the expense. In each case, there is a very sharp transition from passband to reject band.

**[0007]** Figure 3 illustrates the structure and the frequency response for a prior art lattice circuit. Far out of band, the lattice has excellent rejection. However, the near band rejection is very slow. This makes the lattice unusable for circuits requiring close in rejection. This circuit has no fly back at all. Once beyond the passband, the rejection simply increases, at least to the level where other circuit parasitics dominate.

### SUMMARY

**[0008]** In a first embodiment, an N-stage ladder circuit is serially connected to a bridge lattice circuit. The N-stage ladder circuit receives differential inputs, e.g. mixers, while the bridge lattice circuit outputs a singled end output, e.g. amplifier. In a second embodiment, a bridge lattice circuit is serially connected to an N-stage ladder circuit. The bridge lattice circuit receives a differential source while the N-stage ladder circuit drives a differential output load.

**[0009]** In either embodiment, it is preferable that a film bulk acoustic resonator (FBAR) be used in the combination ladder and lattice structure. This provides the necessary band-pass functionality and makes the transition from differential to single ended load where necessary.

### BRIEF DESCRIPTION OF THE DRAWINGS

#### [0010]

Figures 1A-B illustrate prior art film bulk acoustic resonator (FBAR) filters.

Figures 2A-E illustrate prior art ladder circuits.

Figure 3 illustrates a prior art lattice circuit.

Figure 4 illustrates a schematic diagram of the present invention.

Figure 5 illustrates the performance simulation for the circuit shown in Figure 4.

### DETAILED DESCRIPTION OF THE DRAWINGS

**[0011]** The present invention is a resonator-based filter that may be used in a differential circuit or when the circuit must both filter and convert from differential to single-ended. A ladder and lattice structure are combined

into one filter to get the fast transition of the ladder with the far out of band rejection of the lattice, as shown in Figure 4.

**[0012]** An N-stage ladder circuit is serially connected to a bridge lattice circuit at nodes A and B. For each step of the ladder, the rails are a pair of FBARs at the first resonant frequency ( $F_A$ ) and the rung is an FBAR at the second resonant frequency ( $F_B$ ). The lattice circuit is a ring of alternating FBARs at  $F_A$  and FBARs at  $F_B$ . The differential output is shown at nodes C and D.

**[0013]** Figure 5 is a performance simulation for the circuit shown in Figure 4. The simulation shown assumes an ideal balance in the input circuit. In reality, there is some imbalance. In the present embodiment, an imbalance results in reduced differential rejection. In this unbalanced state, the filter puts the extra energy into the common mode.

**[0014]** This phenomenon is evident in the phase response of the filter. In the passband, each arm is  $180^\circ$  out of phase. When balanced, each arm is still  $180^\circ$  out of phase in the reject band. However, when unbalanced, two changes happen in the reject band. First, the amplitude attenuation is reduced, that is the rejection is less. Second, the phase shifts in the reject band until each arm is in phase. This in phase portion of the signal is the common mode and so would be rejected by the common mode rejection of the load.

**[0015]** The net rejection has two components. The first is the normal amplitude reduction of any filter. The second is a combination of how much of the reject signal is put into common mode, and how much common mode rejection is in the load. If the load has infinite CMRR, then the circuit is immune to source imbalance.

**[0016]** In current handsets, the antenna is single-ended. The base band analog portion of the radio is differential. A differential circuit is inherently less sensitive to interference, and thus allows for higher levels of integration. At some point in the transmit arm of the radio, there is transition from single ended to differential, or vice versa. This transition must be handled with minimum losses and expense. There are three techniques for dealing with this transition.

**[0017]** With the first technique, the differential nature of the load or source may be discounted. One of the two terminals can be grounded. This results in half the power being wasted. Far from the antenna, this can be a fine choice. However, when placed near the beginning of the receiver, this will cause an unacceptable increase in Noise Figure, decreasing sensitivity. Too far towards the end of the transmitter, and there will be an unacceptable waste of current and thus battery life.

**[0018]** Traditionally, this is remedied by the use of a balun (BALance/UNbalance). Use of a balun structure is the second technique. A balun is low-loss and may be placed anywhere in the radio. However, its bulk and expense limits its commercial viability. The third technique, a lumped equivalent balun (LE balun) has as few as three reactive elements, e.g. two inductors and a ca-

pacitor. This technique is very sensitive to component value and variation, and has proven largely impractical.

**[0019]** Unlike the prior art, the present invention, a combination differential ladder and lattice filter, may be driven differentially into a single-ended load, without incurring a loss of half of the signal. The circuit is still sensitive to the balance of the source. Since a single-ended load is being driven, there is no common mode rejection. Consequently, as the source becomes more unbalanced, the filter rejection decreases. This filter requires more care to ensure that the source is sufficiently balanced to enable adequate rejection. Specifically, one may need to tune the individual arms of the differential source, balancing this source to ensure sufficient rejection.

## Claims

1. A filter balun comprising:

a N-stage differential ladder filter having at least two inputs and an output; and  
a bridge circuit, receiving the output of the N-stage differential ladder filter, having an output.

2. A filter balun, as defined in claim 1, wherein the N-stage differential ladder filter and the bridge circuit include film bulk acoustic resonators.

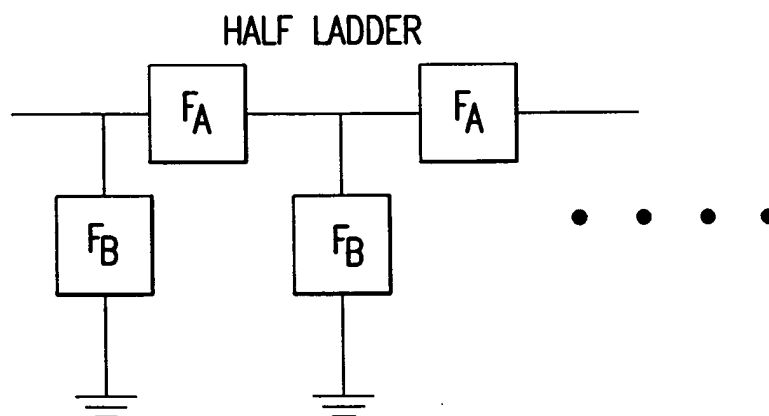


FIG.1A  
PRIOR ART

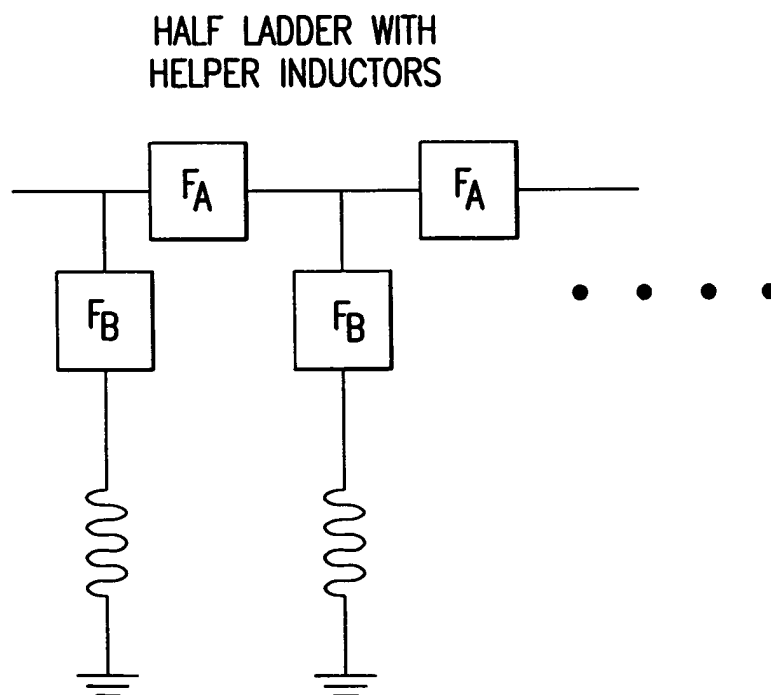


FIG.1B  
PRIOR ART

UNREFERENCED LADDER SECTION

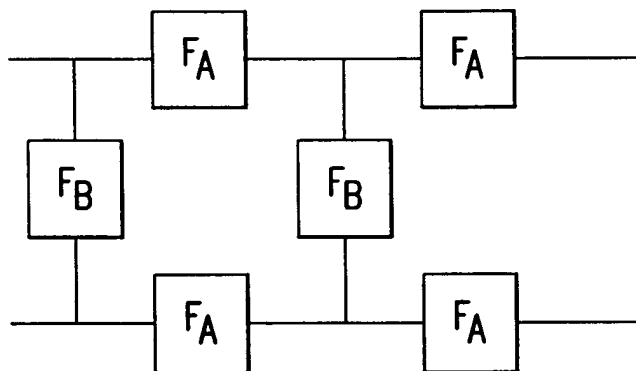


FIG.2A

LADDER SECTION WITH GROUND REFERENCE

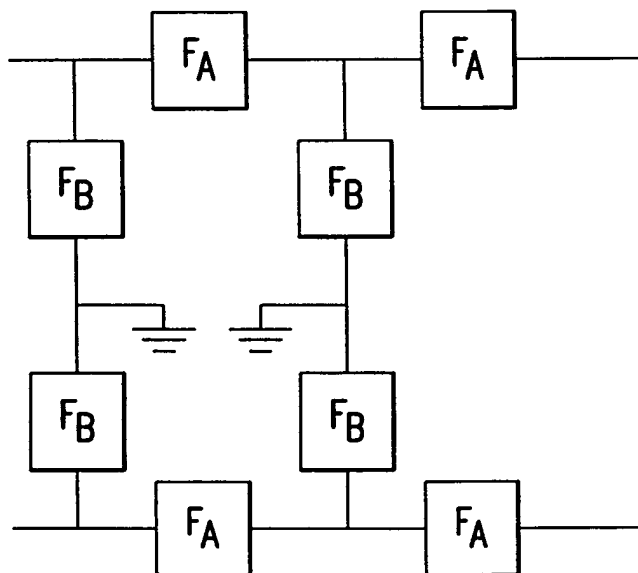


FIG.2B

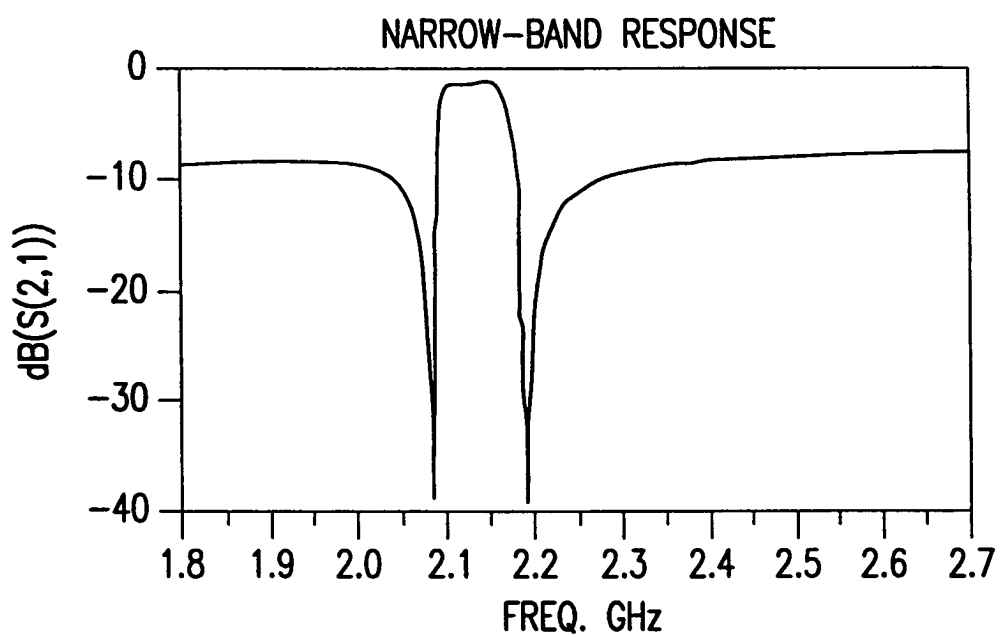


FIG.2C

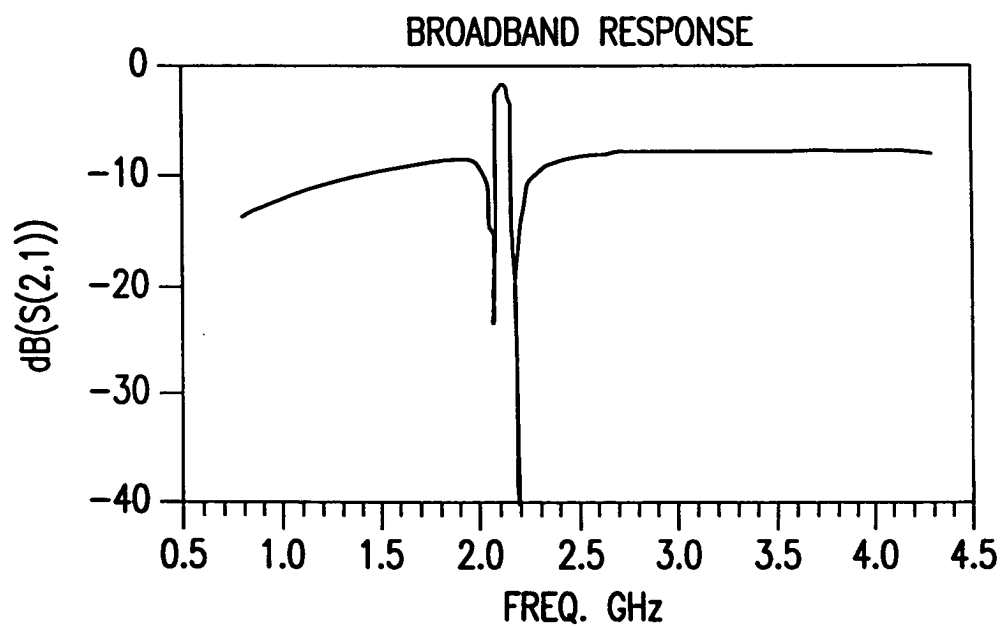


FIG.2D

LADDER SECTION WITH  
HELPER INDUCTORS

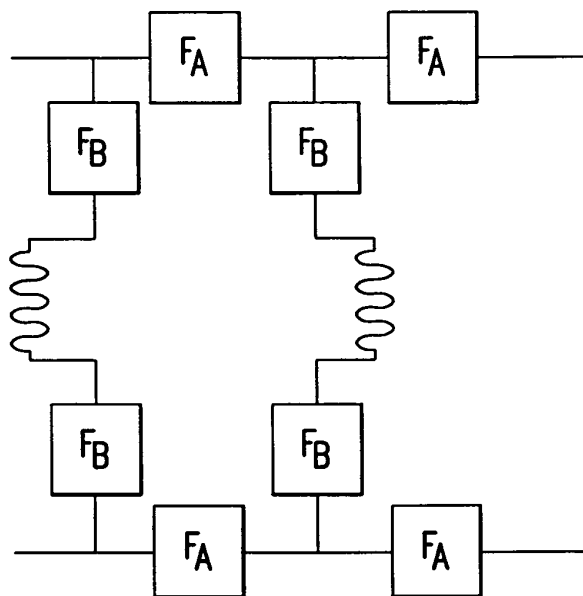


FIG.2E

LADDER SECTION WITH HELPER  
INDUCTORS AND GROUND REFERENCE

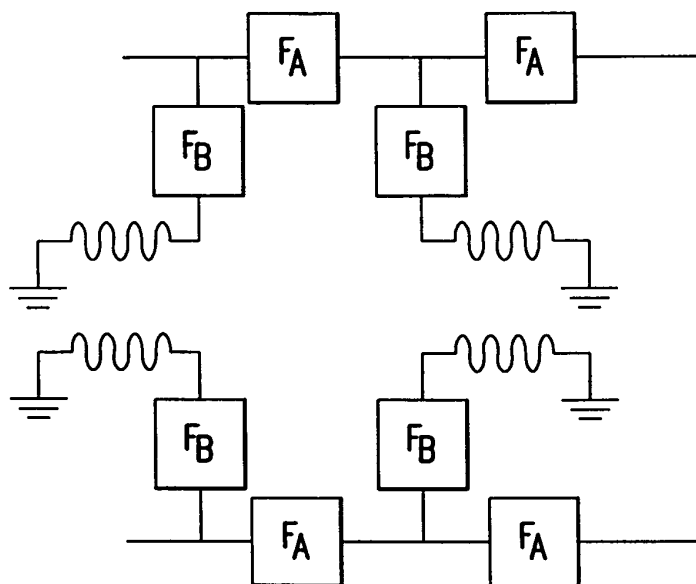
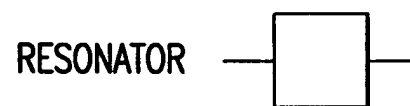
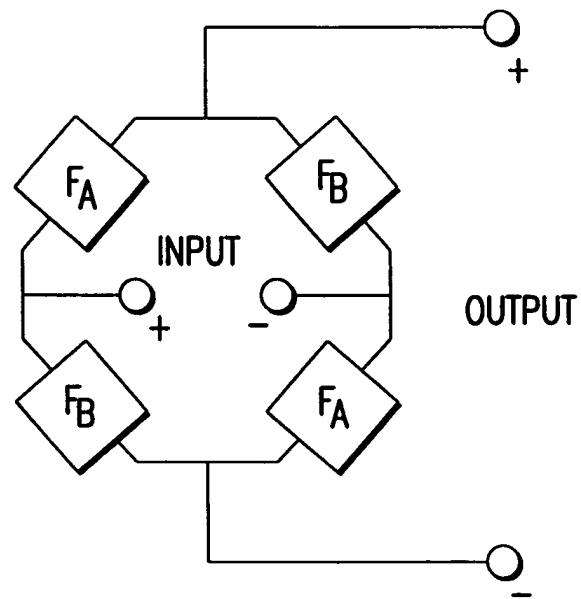


FIG.2F

LATTICE FILTER STRUCTURE



$F_A$  OR  $F_B$  REFER TO DIFFERENT  
RESONANT FREQUENCIES

FIG.3A  
PRIOR ART

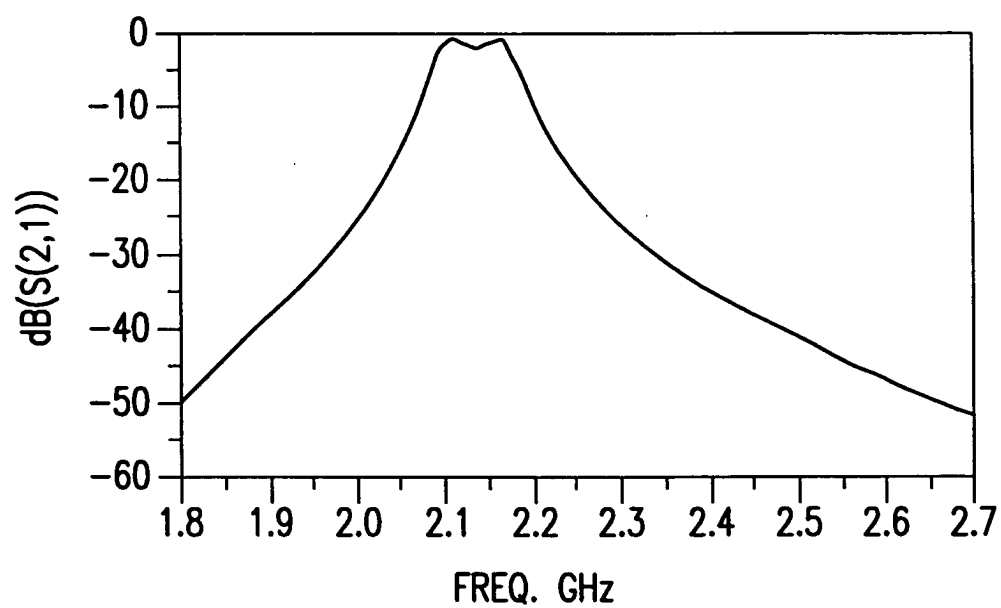


FIG.3B

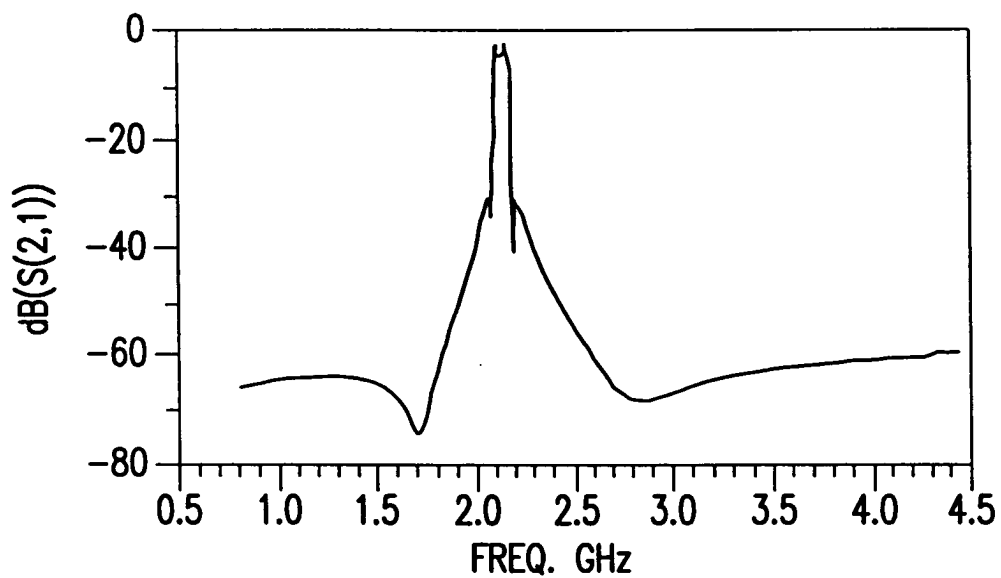


FIG.3C

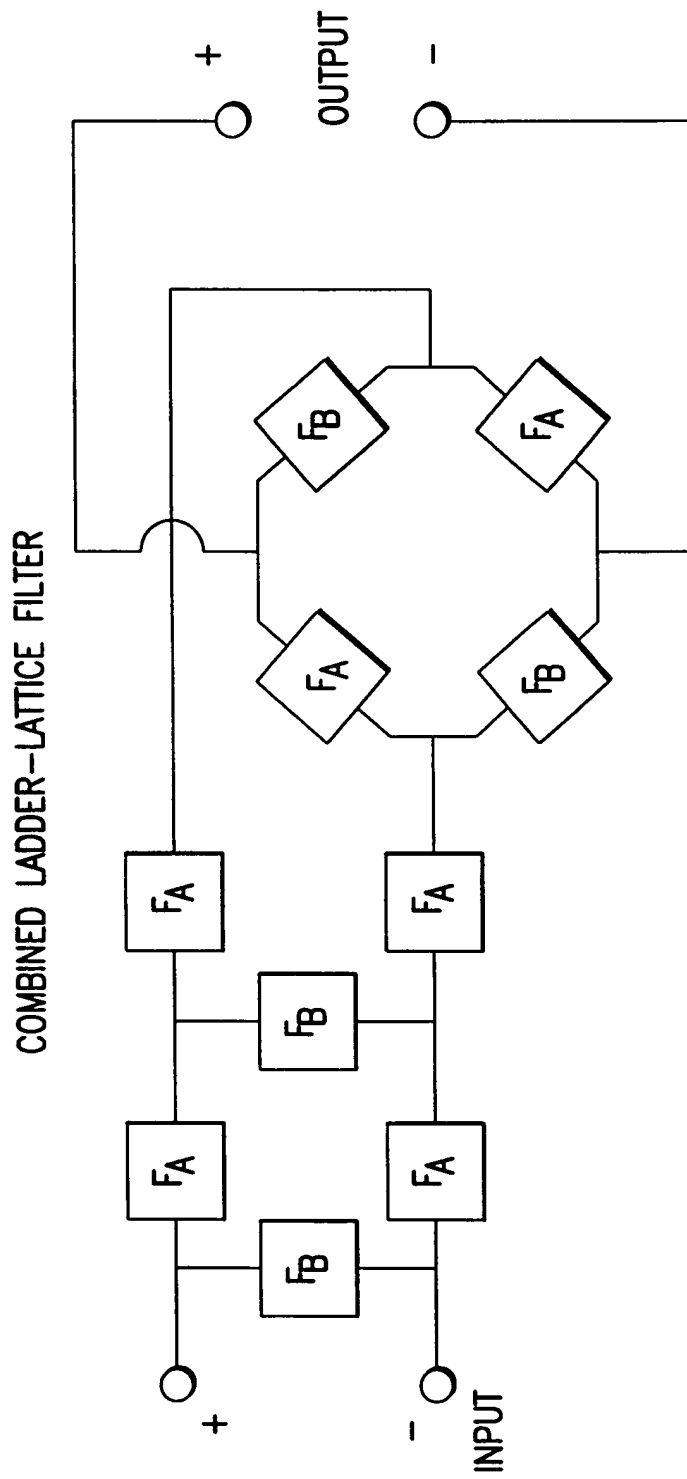


FIG.4A

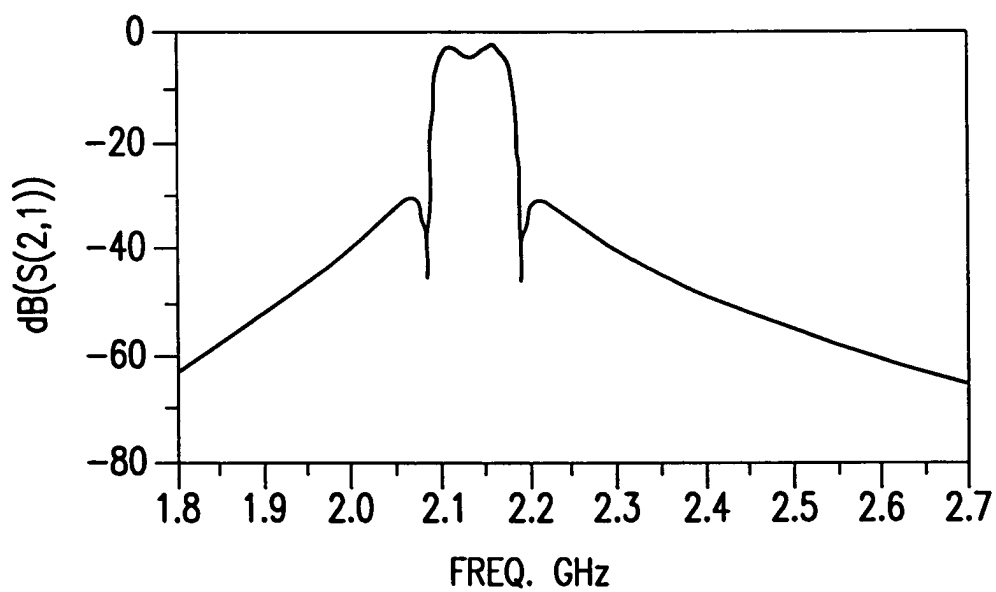


FIG. 4B

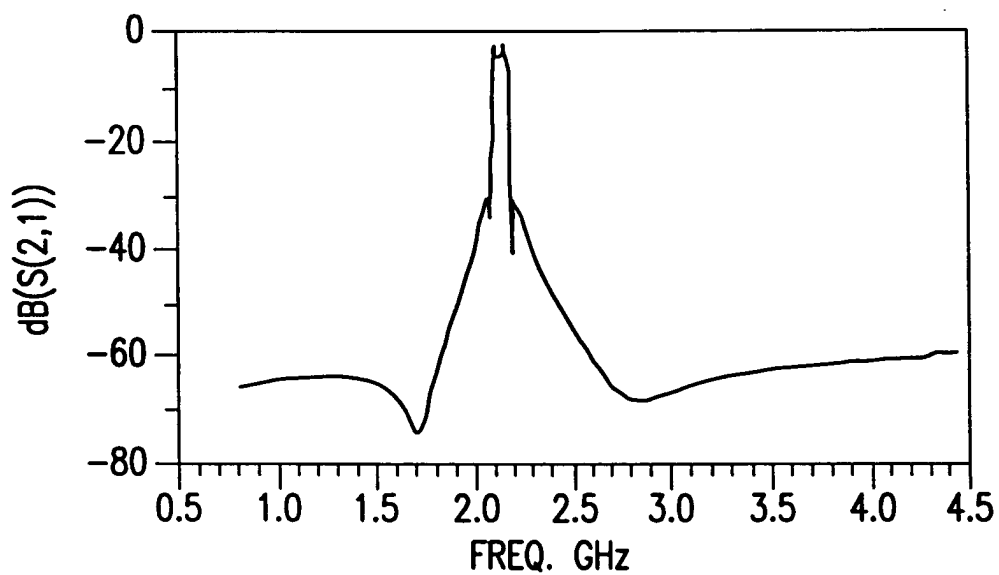


FIG. 4C

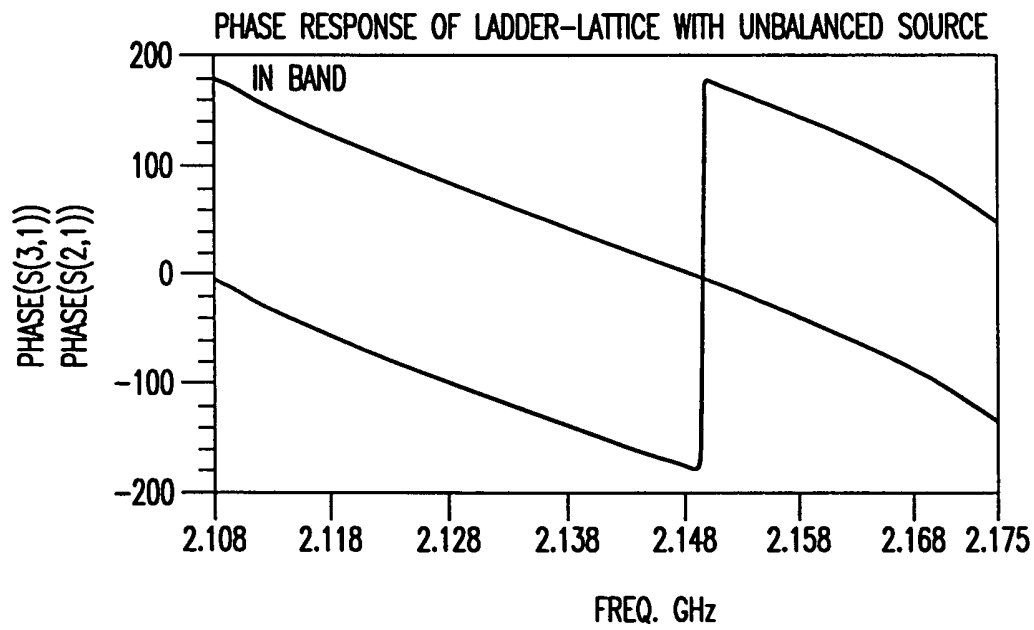


FIG.5A

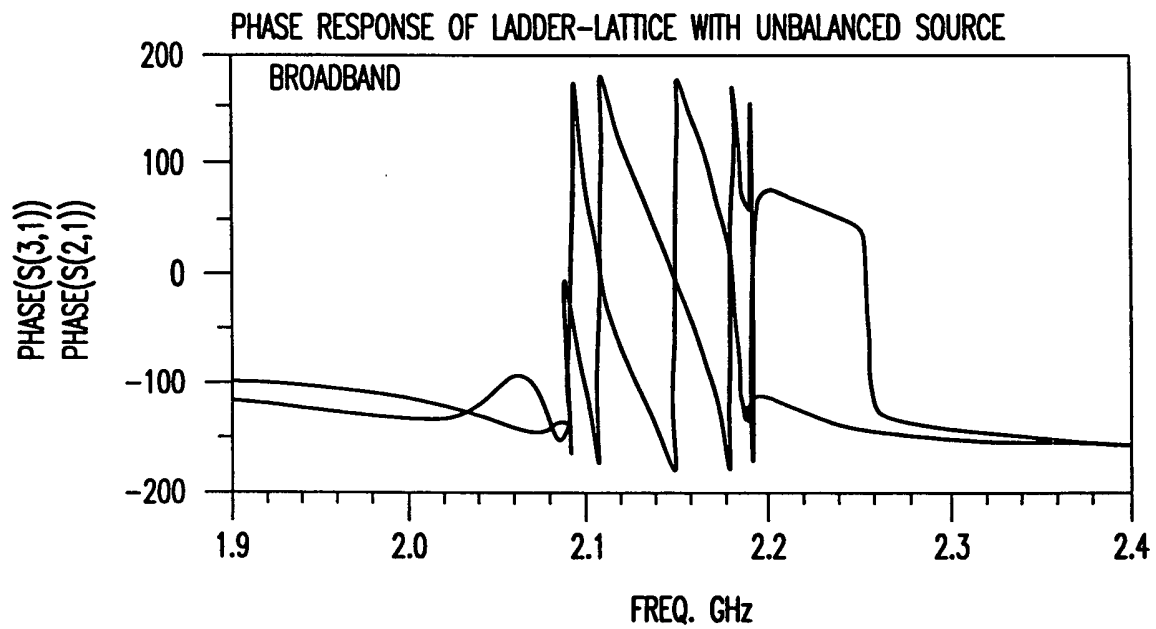


FIG.5B